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THREE-DIMENSIONAL STRUCTURE  
[SANJIGEN KOUZOUTAI]

KATSUMI YAMAGUCHI

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INVENTOR(S) (72) : Katsumi Yamaguchi

APPLICANT(S) (71) : Jibetsuku  
International Corp.

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Specification

[Claims]

[Claim 1]

A three-dimensional structure produced by lamination of granular metallic materials, wherein the granular metallic materials are bonded by fusion.

[Claim 2]

The three-dimensional structure according to claim 1, wherein each one of the two or more metallic materials is laminated as a separate granulate.

[Claim 3]

A three-dimensional structure produced by lamination of granulates via bonding by fusion, wherein electrically conductive materials and electrically nonconductive materials are each laminated as a separate granulate to form a three-dimensional electrical circuit.

[Claim 4]

A three-dimensional structure produced by lamination of granulates via bonding by fusion, wherein two or more materials are each laminated as a separate granulate to form a three-dimensional functionally gradient composite.

[Claim 5]

A three-dimensional structure produced by lamination of granulates via bonding by fusion, wherein a transparent resin and an opaque resin are each laminated as a separate granulate to form a three-dimensional model.

[Claim 6]

The three-dimensional structure according to any of claims 1 through 5, wherein the granulates have the same size.

[Claim 7]

A process for the fabrication of a three-dimensional structure, wherein metallic materials are melted by heating, piezoelectrically sprayed, deposited, and solidified in granular form.

[Claim 8]

A process for the fabrication of a three-dimensional structure, wherein metallic materials are sprayed by a discharge of electric current, deposited, and solidified in granular form.

[Claim 9]

A process for the fabrication of a three-dimensional structure, wherein granular metallic materials are laminated by bonding together via fusion.

[Detailed Description of the Invention]

[0001]

[Field of the Invention]

The present invention relates to a three-dimensional structure that can be employed, for example, for three-dimensional models and components of micro-mechanical devices.

[0002]

[Prior Art]

In recent years, various attempts have been made at prototyping, in which various three-dimensional shapes are built based on engineering drawings or computer-generated information. The methods which have been developed include stereo lithography, in which a photosensitive resin is exposed to light and laminated in layers, methods, in which thin layers are cut with a laser and stacked, and methods, in which powders are hardened by irradiation with a laser, etc.

[0003]

[Problem to be solved by the Invention]

However, in the above-described methods, usable materials are limited to a few resins, etc., and metallic materials, in particular, are extremely difficult to use. When using metallic materials, it is contemplated to employ

methods, in which metallic powders are bonded with binders. In such methods, however, it is difficult to achieve sufficient accuracy and strength and, in particular, it is extremely difficult to use dissimilar materials in a composite manner.

[0004]

Thus, it is an object of the present invention to solve the above-described problems and provide a three-dimensional structure, in which various materials, especially metals, are utilized. Further, it is an object of the present invention to provide a three-dimensional structure, in which dissimilar materials are utilized in a composite manner.

[0005]

[Means for Solving the Problem]

The three-dimensional structure according to claim 1 is a three-dimensional structure produced by lamination of granular metallic materials, wherein the granular metallic materials are bonded by fusion. The three-dimensional structure according to claim 2 is the three-dimensional structure according to claim 1, wherein each one of the two or more metallic materials is laminated as a separate granulate. The three-dimensional structure according to claim 3 is a three-dimensional structure produced by

lamination of granulates via bonding by fusion, wherein electrically conductive materials and electrically nonconductive materials are each laminated as a separate granulate to form a three-dimensional electrical circuit. The three-dimensional structure according to claim 4 is a three-dimensional structure produced by lamination of granulates via bonding by fusion, wherein two or more materials are each laminated as a separate granulate to form a three-dimensional functionally gradient composite. The three-dimensional structure according to claim 5 is a three-dimensional structure produced by lamination of granulates via bonding by fusion, wherein a transparent resin and an opaque resin are each laminated as a separate granulate to form a three-dimensional model. The three-dimensional structure according to claim 6 is the three-dimensional structure according to any of claims 1 through 5, wherein the granulates have the same size. In the process for the fabrication of a three-dimensional structure according to claim 7, metallic materials are melted by heating, piezoelectrically sprayed, deposited and solidified in granular form. In the process for the fabrication of a three-dimensional structure according to claim 8, metallic materials are sprayed by a discharge of electric current, deposited, and solidified in granular

form. In the process for the fabrication of a three-dimensional structure according to claim 9, granular metallic materials are laminated by bonding together via fusion.

[0006]

[Embodiments of the Invention]

Based on using metallic materials in granular form and laminating the granulates by fusion, the inventive three-dimensional structure permits accurate fabrication of minute components, e.g. such as those of micro-mechanical devices and the like. Further, composites utilizing two or more metallic materials can also be readily fabricated because each of the materials is laminated by fusion as a separate granulate. Accordingly, the present invention allows for three-dimensional electrical circuits to be formed by using electrically conductive materials and electrically nonconductive materials, permits fabrication of three-dimensional functionally gradient composites by laminating two or more materials, or makes it possible to form three-dimensional models by using transparent resins and opaque resins. In this manner, the three-dimensional structure of the present invention allows for obtaining products directly, without relying on processes such as transfer, etc., and, at the same time, permits fabrication

of composite products that could not be fabricated using processes such as transfer. It should be noted that, due to the same size of the granulates, translational movement during the lamination of the granulates can be effected at a constant speed and, as a result, lamination can be performed quickly and easily and dimensional accuracy in the height direction can be readily controlled. Further, as far as methods of laminating metallic materials in granular form are concerned, one method that can be easily implemented, in particular when using metallic materials with low melting points, consists in melting the materials and spraying them by piezoelectric means. Another method, which is especially preferable when using metallic materials with high melting points, consists in spraying the materials by a discharge of electric current. Producing the three-dimensional structure of the present invention by bonding such granular metallic materials together by means of fusion permits lamination without using special bonding materials, etc., and makes it possible to ensure sufficient accuracy and strength.

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[0007]

[Working Examples]

First of all, some fundamental concepts associated with the three-dimensional structure fabricated in accordance with the present invention will be explained with reference to drawings. FIGs. 1 through 3 are conceptual block diagrams to explain the fabrication process, and FIG. 4 is an oblique view illustrating a three-dimensional structure fabricated in accordance with this process. In the present invention, lamination is performed by ejecting molten material from a nozzle 10 as granulate 20 and causing it to adhere to already-deposited/solidified granulate 20 in a state, in which at least its surface is molten. It should be noted that the already-deposited granulate 20 does not necessarily have to be solid and may still be in a somewhat molten condition. There is provided a structure supporting means 30, i.e. a surface, on which the granulate 20 is laminated. It should be noted that, in order to fabricate a three-dimensional structure from such granulate 20, it is necessary to move the structure supporting means 30 relative to the nozzle 10, or the nozzle 10 relative to the structure supporting means 30, in a direction parallel or transverse thereto, and explanations provided herein are based on the assumption

that the nozzle 10 moves in a direction parallel or transverse to the structure supporting means 30.

[0008]

FIG. 1 illustrates a state, in which a planar structure 21, which constitutes a first layer, is being formed. Namely, as shown in the same figure, rows between the first row, i.e. scan line 21A, and the third row, i.e. scan line 21D, have already been formed, and the fourth row, i.e. scan line 21E, is being formed. Accordingly, at this point the nozzle 10 is moving in a direction normal to the surface of the page while spraying the granulate 10. It should be noted that the nozzle 10 is maintained at a distance  $L$  from the structure supporting means 30. FIG. 2 illustrates a state, in which a planar structure constituting a second layer is about to be formed after forming the planar structure 21 of the first layer. It should be noted that, in order to form the planar structure of the second layer after forming the planar structure 21 of the first layer, the nozzle 10, along with moving in a two-dimensional manner in a direction parallel to the structure supporting means 30, moves in a transverse direction so as to provide the distance  $L$  between the nozzle and planar structure 21 of the first layer. FIG. 3 illustrates a state, in which the planar structure 22 of

the second layer has been formed on the surface of the planar structure 21 of the first layer and the first row of a third layer, i.e. scan line 23A, is being formed. At such time, the nozzle 10 is also moved in such a manner that the distance L is ensured between it and the planar structure 22 of the second layer. As described above, a three-dimensional structure is fabricated by performing lamination via adhesion of successive layers of the molten granulate 20. FIG. 4 illustrates a three-dimensional structure fabricated by doing so. As shown in the figure, this is a pyramidal structure which, in order outward from the bottom portion, is made up of the planar structure 21 of the first layer, planar structure 22 of the second layer, planar structure 23 of the third layer, and so on.

[0009]

In addition to solder, iron, cobalt, copper, and other metallic materials, resins and waxes can be used as the building materials of the three-dimensional structure. When laminating two metallic materials, it is preferable to use metals whose melting points are not far removed or metals that can be easily bonded, with appropriate combinations including, for example, iron and copper, iron and nickel, iron and cobalt, copper and zinc, copper and nickel, etc. When laminating resins together with metals,

it is preferable to use thermosetting resins. In addition to solder, silver and nickel are preferable as metals laminated together with resins. In particular, if the metallic material is a low-melting material such as solder, etc., it can be liquefied by heating to a temperature above its melting point and the molten solder can be sprayed using piezoelectric elements. Further, in case of iron, cobalt, copper, and other high-melting materials, effective methods, as described below, include spraying by a discharge of electric current and spraying using laser irradiation.

[0010]

Next, referring to FIG. 5, explanations will be given regarding a configuration used in a working example of a fabrication device used to fabricate the inventive three-dimensional structure. It should be noted that while the present working example describes a method of fabricating a three-dimensional structure made of iron material, the three-dimensional structure fabricated in this method has a structure that cannot be produced by laminating iron material alone, namely, a structure, in which the upper-layer portion is wider than the lower-layer portion. Accordingly, the aluminum material that is laminated together with the iron material is subsequently removed.

There is provided a material ejecting means 11, which employs a discharge of electric current to spray an iron granulate 24A, and a material ejecting means 12, which employs a discharge of electric current to spray aluminum granulate 25A. Each one of them is made up of, respectively, discharging circuits 11A, 12A, ejection nozzles 11B, 12B, electrodes 11C, 12C, etc. The structure supporting means 31 has a surface, on which the granulates 24A, 25A are laminated, with this surface being adapted to be movable in a direction parallel or transverse to the material ejecting means 11, 12. It should be noted that the granulates 24B, 25B on top of the structure supporting means 31 are granulates that have already been laminated, i.e. deposited and solidified. There is provided a material feeding means 41, which supplies iron to the material ejecting means 11, and a material feeding means 42, which supplies aluminum to the material ejecting means 12. Using structure data associated with three-dimensional structure stored in a data storing means 60, a control means 50, along with outputting signals describing the movement of the structure supporting means 31, outputs ejection signals intended for the material ejecting means 11, 12. As described herein, the ejection signals outputted to the material ejecting means 11, 12 can vary

the size and number of the ejected particles of the granulates 24A, 25A by permitting changes in the width and period of the discharge pulses. Further, in the present working example, the structure data associated with the three-dimensional structure stored in the data storing means 60 is shape-related. However, in case of two or more composite or gradient materials, material-related data is used as well. A detecting means 70 detects the state of the three-dimensional structure being fabricated, in particular its height dimensions. A data comparing means 80 compares data detected by the detecting means 70 with the structure data stored in the data storing means 60. Based on the comparison results of the data comparing means 80, a modified signal is outputted to the control means 50 if the condition of the three-dimensional structure being fabricated is different from what is expected.

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[0011]

A method of controlling the above-described fabrication device is explained below. First of all, data for each layer associated with the three-dimensional structure to be fabricated is transmitted from the data storage means 60 to the control means 50. The control means outputs a signal that moves the structure supporting

means 31 in a direction parallel to the material ejecting means 11, 12. In locations, in which lamination of the three-dimensional structure is performed, a signal is outputted to the material ejecting means 11 so as to cause it to spray the iron granulate 24A and, on the other hand, in locations, in which lamination of the three-dimensional structure is not performed, a signal is outputted to the material ejecting means 12 so as to cause it to spray the aluminum granulate 25A. In this manner, each layer is laminated by spraying either the iron granulate 24A or the aluminum granulate 25A. When fabricating more precise three-dimensional structures, the stacked configuration is detected by the detecting means 70 on a layer-by-layer basis, comparison with the data of the data storing means 60 is performed by the comparing means 80, and the results are outputted as a modified signal to the control means 50. At such time, if the amount is insufficient, the control means 50 adds a correction to supplement the lacking portion. However, if a predetermined amount is exceeded, then a correction is made either by laminating no granulate during the lamination of the next layer, or by making the size of the granulate smaller than usual. It should be noted that, after laminating a layer, the distance from the material ejecting means 11, 12 to the lamination surface is

maintained constant by moving the structure supporting means 31 in the transverse direction. After forming a laminate using an iron material and an aluminum material as described above, the aluminum material is dissolved with an etchant, yielding a three-dimensional structure that contains only the iron material. In addition, in FIG. 5, which is a conceptual diagram, the direction of feed of the material is transverse to the ejection orifices of the nozzles 11B, 12B, as a result of which the ejection distance of the material can be maintained constant and uniform granulate can be obtained. Further, fabrication can be sped up by using multiple nozzles simultaneously for the same material.

[0012]

Application examples of three-dimensional structures utilizing two or more materials will be explained next. First of all, let us refer to FIG. 6, which is an oblique view of a three-dimensional structure used to form an integral three-dimensional electrical circuit. As shown in the same figure, the three-dimensional electrical circuit is formed from an electrically nonconductive material 26A and electrically conductive materials 26B-26D. As shown herein, the electrically conductive materials are used for the wiring portion 26B, core portion 26C, and coil portion

26D. It should be noted that a thermoplastic resin etc. is used as the electrically nonconductive material 26A and a metal is used as the electrically conductive material. However, when laminating it together with a thermoplastic resin, etc., it is more appropriate to use a low-melting material, such as solder, aluminum, and the like. Further, FIG. 7 is an oblique view of a three-dimensional structure used to form a three-dimensional functionally gradient composite. As shown in the same figure, when using granulates 27A, 27B composed of two or more materials, the boundary between one material, e.g. 27A, and the other material, i.e. 27B, gradually changes the mixing ratio and imparts gradient functionality. Further, FIG. 8 is a front view of a three-dimensional structure used to form a three-dimensional model of a human head. As shown in the same figure, it is formed, for instance, from a transparent resin, 28A, and an opaque resin, 28B. A more detailed three-dimensional model can be fabricated by using multiple resins of different colors instead of the opaque resin.

[0013]

[Effects of the Invention]

As described above, the present invention permits fabrication of three-dimensional structures by laminating granulates layer-by-layer, thereby permitting fabrication

of three-dimensional images based on computer-aided image analysis, transmission and other techniques. Laminating granulates by fusion permits accurate fabrication of minute parts, such as, for instance, those of micro-mechanical devices and the like. Further, composites utilizing two or more metallic materials can be readily fabricated because each of the materials is melted and laminated as a separate granulate. Accordingly, the present invention allows for three-dimensional electrical circuits to be formed by using electrically conductive materials and electrically nonconductive materials, permits fabrication of three-dimensional functionally gradient composites by laminating two or more materials, or makes it possible to form three-dimensional models by using transparent resins and opaque resins. In this manner, the three-dimensional structure of the present invention allows for obtaining products directly, without relying on processes such as transfer, etc., and, at the same time, permits fabrication of composite products that could not be fabricated using processes such as transfer.

[Brief Description of the Drawings]

[Fig. 1]

A conceptual block diagram to explain a working example of a fabrication process used to fabricate the inventive three-dimensional structure.

[Fig. 2]

A conceptual block diagram to explain a working example of a fabrication process used to fabricate the inventive three-dimensional structure.

[Fig. 3]

A conceptual block diagram to explain a working example of a fabrication process used to fabricate the inventive three-dimensional structure.

[Fig. 4]

An oblique view of a three-dimensional structure fabricated by the same fabrication process.

[Fig. 5]

A block diagram of a working example of a fabrication device used to fabricate the inventive three-dimensional structure.

[Fig. 6]

An oblique view of the inventive three-dimensional structure used to form an integral three-dimensional electric circuit.

[Fig. 7]

An oblique view of the inventive three-dimensional structure used to form a three-dimensional functionally gradient composite.

[Fig. 8]

A front view of the inventive three-dimensional structure used to form a three-dimensional model of a human head.

[Description of the Reference Numerals]

20. Granulate.

24A. Iron granulate.

25A. Aluminum granulate.

26A. Electrically nonconductive material.

26B. Wiring portion (electrically conductive material).

26C. Core (electrically conductive material).

26D. Coil (electrically conductive material).

26B. Wiring portion (electrically conductive material).

27A. Granulate.

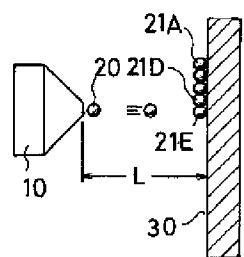
27B. Granulate.

28A. transparent resin.

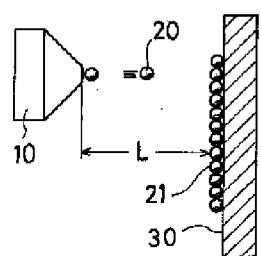
28B. Opaque resin.

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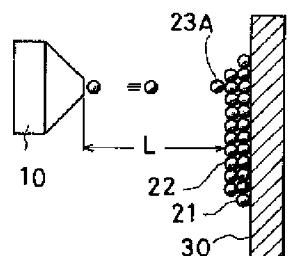
[Fig. 1]



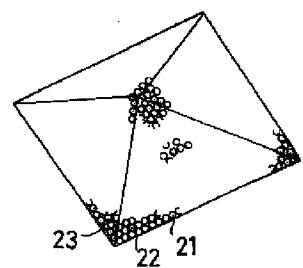
[Fig. 2]



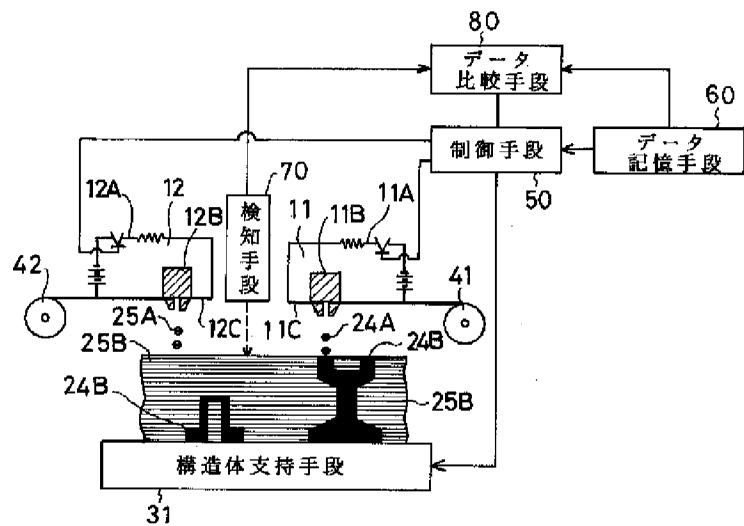
[Fig. 3]



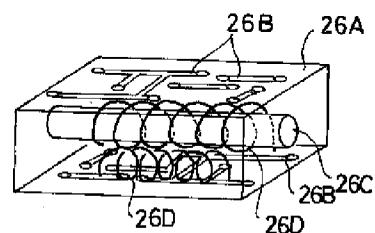
[Fig. 4]



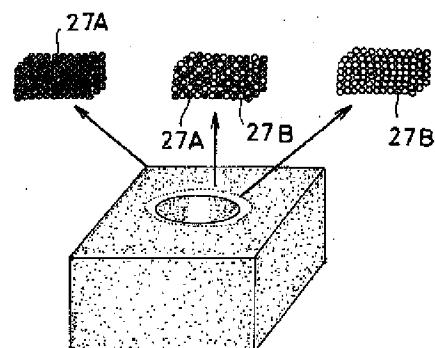
[Fig. 5]



[Fig. 6]



[Fig. 7]



[Fig. 8]

